



Variations of the wake height over the Bolund escarpment

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Variations of the wake height over the Bolund escarpment

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$$f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^i}{i!} f^{(i)}(x)$$

$$\int_a^b \varepsilon \Theta + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$

$$\chi^2 \Sigma!$$



- **Flow over complex terrain** creates complex flow structures that stress wind turbines and influence power production



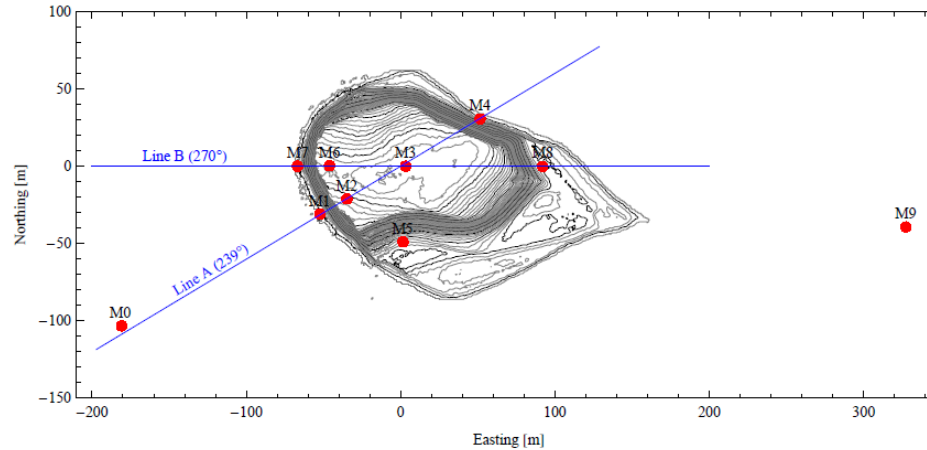
- Important to characterize flow over complex terrain
- Numerical (CFD, WAsP) and physical (wind tunnel) modelling
 - Real world reference cases for validation



Bolund in the Roskilde Fjord



Bolund as a baseline reference case



Experiment Date:

Dec 2007 – Feb 2008

Experiment Set-up:

10 masts, equipped with 23 sonics, 12 cups along line A & B, 2 lidars (See: Bechmann et al. 2011, BLM; Berg et al. 2011, BLM)

Flow pattern are observed



Well defined boundary conditions, long upstream fetch



Ideal for validation of numerical / physical models



Measurement of the wake zone ... With a WindScanner

Type

- Laser anemometer
- Windscanner.dk project (DTU Wind Energy)

Mode of measurement

- Continuous wave, coherent Doppler lidar
- Directed by two independently moving prisms

Output

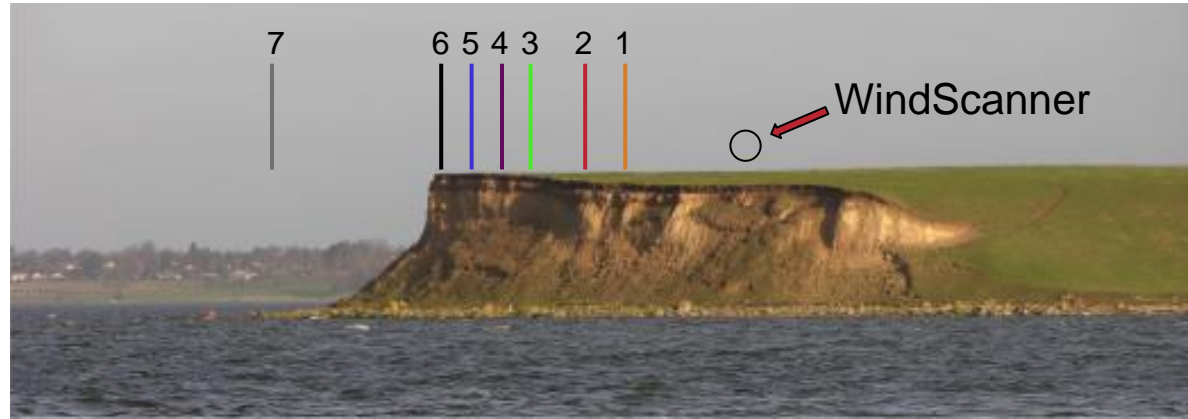
- Line-of-sight velocity
- Data streaming rate of 390 Hz



More information about WIndScanner at DTU
stand Nr: L07



Measurement of the recirculation zone



When

- October 2011, Duration: approx. 24h

How

- Positioning 20 m away from the Bolund escarpment
- Aligned to predominant wind direction, on 270° axis, west facing

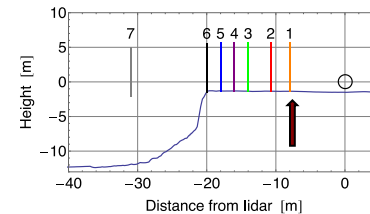
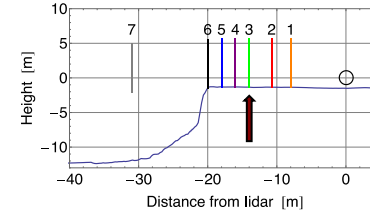
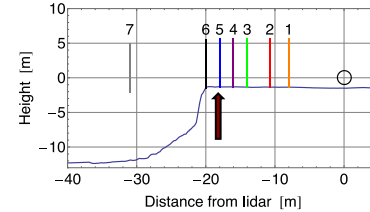
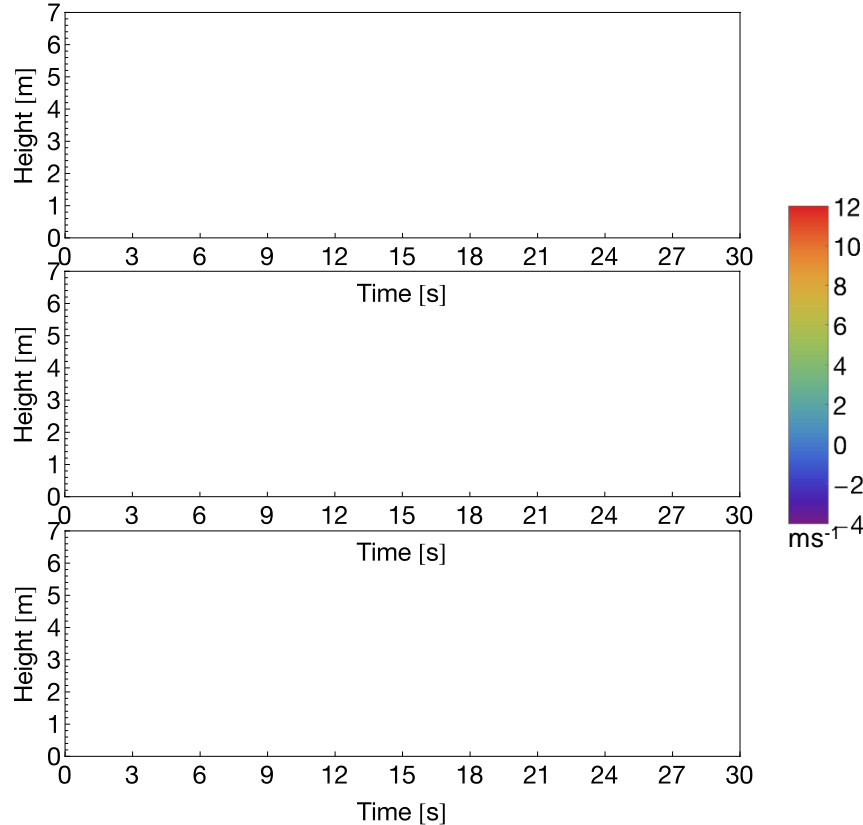
What

- 7 vertical, 7-m tall profiles
- 1 horizontal arc 90 m upstream of Bolund (definition of inflow)



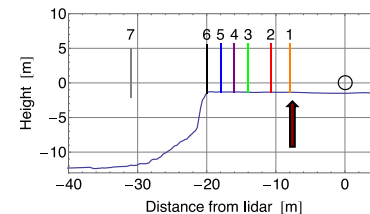
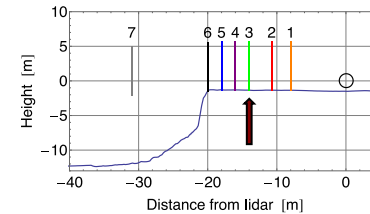
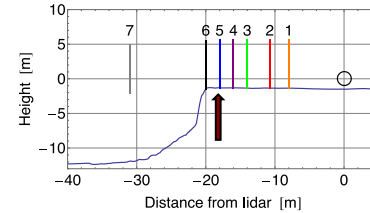
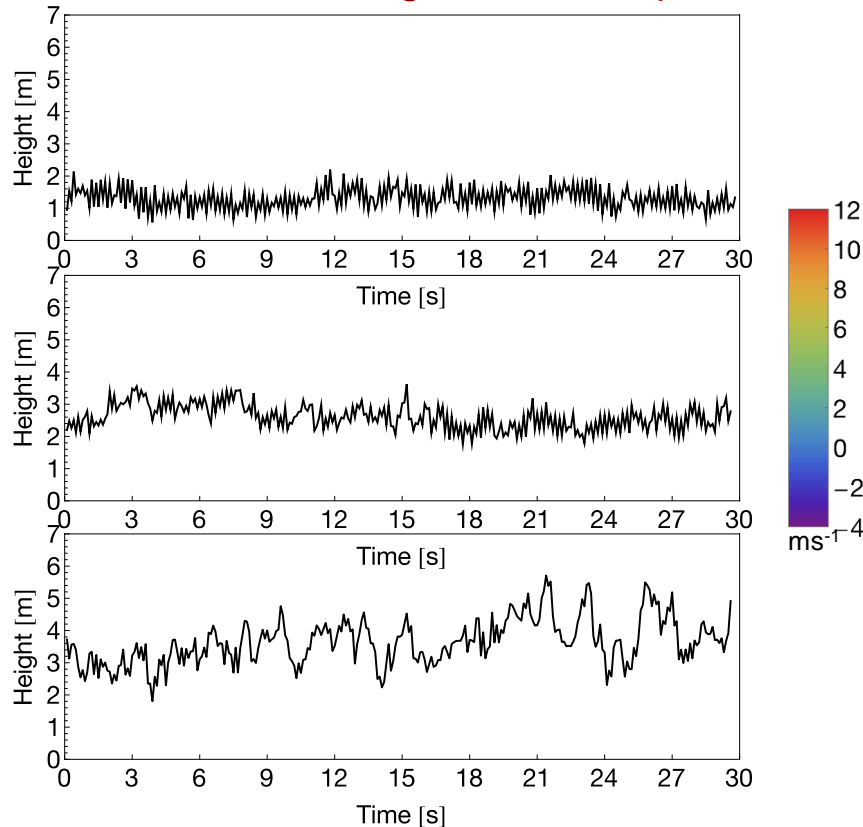
Half a minute scanning data...

390 line-of-sight velocities per second, 0.1 s per vertical profile



Half a minute scanning data... with wake height definition

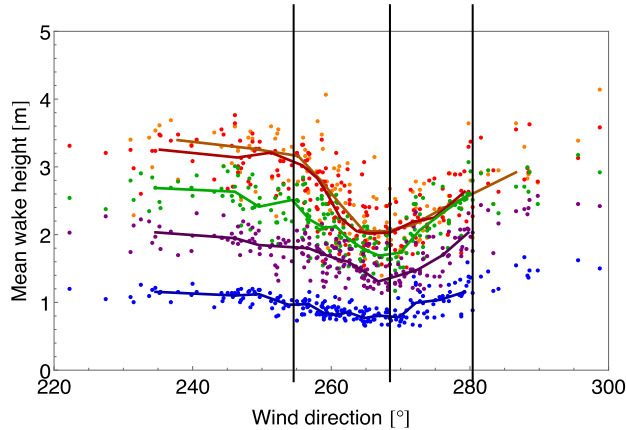
390 line-of-sight velocities per second, 0.1 s per vertical profile



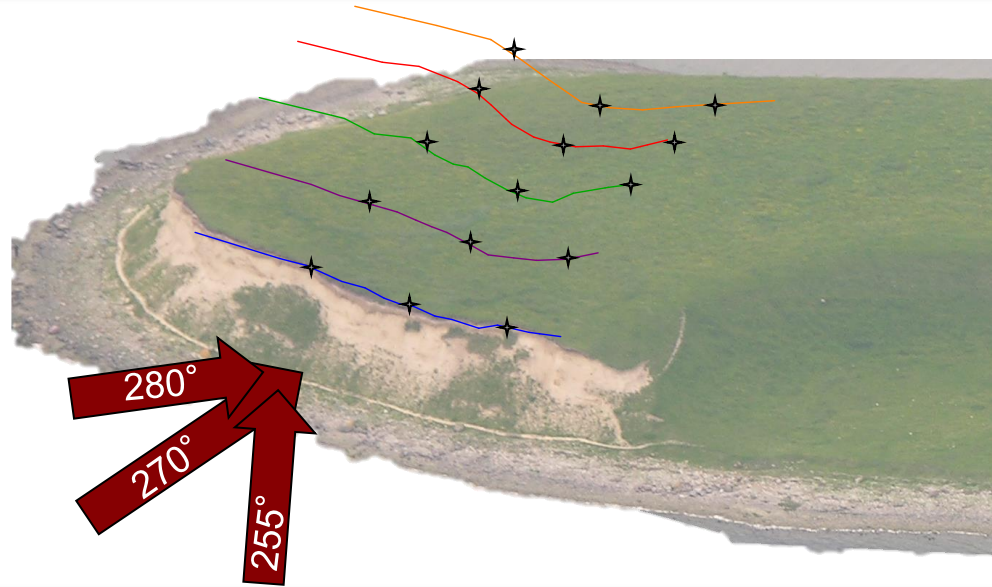
Definition
of wake
height
→
average
over 30 s
scan



The wake height is highly dependent on the wind direction



Lange et al., Variations of the Wake Height over the Bolund Escarpment Measured by a Scanning Lidar, Boundary-Layer Meteorology.



Wake height dependency on distance from escarpment:

- Increasing wake height with distance from escarpment

Wake height dependency on wind direction

- Wind direction deviation from west $\pm 15^\circ$ increase of wake height by 10-70%



Bolund in the WindEEE Dome, University Western Ontario, Canada

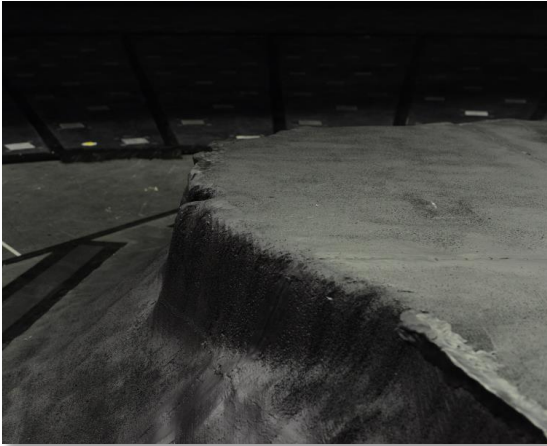


- WindEEE Dome
- Dimensions: 25m in diameter
- Large scale models, manipulation of inflow and boundary conditions



- Bolund model scale: 1:25
- Dimensions: 0,48m high x 3m wide x 4m long

Comparison of the Bolund edge real world vs. model



Bolund model



Real Bolund



Addition of clay to model edge

➤ Model edge is too round

➤ Model edge is SHARPER

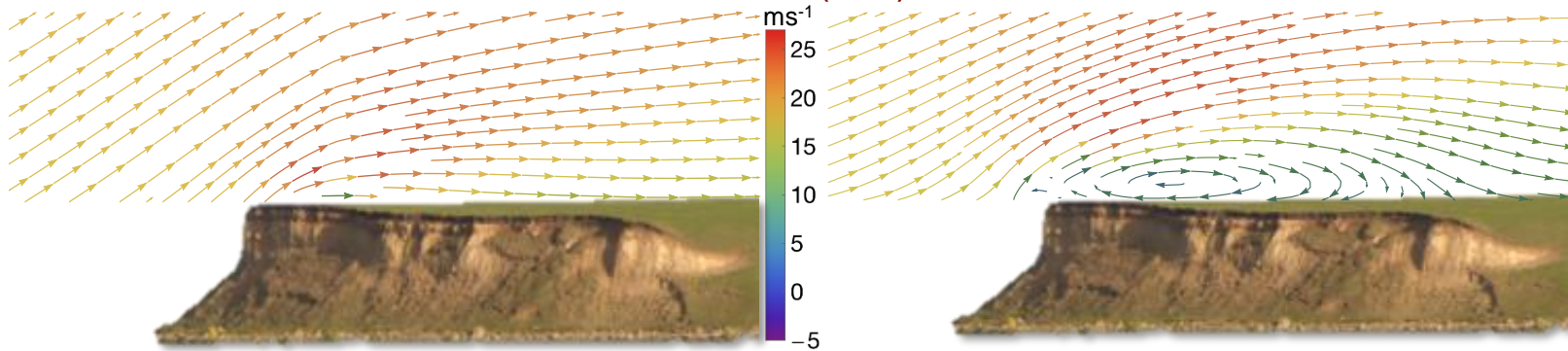


Flow over original edge vs. sharpened edge

Flow visualization with smoke



Measurement (PIV) results



- Smooth flow over edge

- Strong recirculation zone

- High dependency of wake height on wind direction
- Difficult to reproduce real world flow
- Flow is sensitive to small orographic details, such as the edge



Thank you for listening



Thank you to
DTU colleagues, UWO, WindEEE Dome Team

